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APPARATUS AND METHOD FOR CONTROLLING A HYBRID VEHICLE

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part application of commonly owned and assigned U.S. Serial No. 09/870,337 filed May 30, 2001, the contents of which are incorporated herein by reference thereto.

This patent application is related to U.S. Serial Nos. 09/483,986 and 09/551,460 and to U.S. Patent No. 6,254,507, the contents of which are incorporated herein by reference thereto.

TECHNICAL FIELD

The present invention is related to a method and apparatus for controlling a hybrid vehicle.

BACKGROUND OF THE INVENTION

A hybrid vehicle is a vehicle that has two sources of propulsion. A hybrid electric vehicle (HEV) is a vehicle wherein one of the sources of propulsion is electric and the other source of propulsion may be derived from fuel cells or an internal combustion engine (ICE) that burns diesel, gasoline or any other source of fuel. The hybrid vehicle employs an operating system for controlling the alternative sources of propulsion.

An electric motor-generator (MoGen) system replaces the separate starter motor and alternator.

The motor generator or “MoGen” of a hybrid system provides many unique aspects of powertrain control previously unavailable with a conventional or separate engine starter and alternator control scheme. A separate conventional starter control only allows the starter motor to apply

torque to the internal combustion engine during a crank event. A separate alternator control simply charges to a set point voltage.

SUMMARY OF THE INVENTION

The present invention includes a fuel efficient hybrid vehicle having a hybrid propulsion system. The propulsion system includes an internal combustion engine, an electric motor/generator operatively coupled to the internal combustion engine and an electric storage medium and a propulsion system controller for actuating the propulsion system. The propulsion system controller monitors the operating conditions of the hybrid vehicle, and in accordance with these conditions, the controller will vary the state of the propulsion system to one of a plurality of states each of which corresponds to a degree of hybridization of the vehicle.

The hybrid vehicle includes a hybrid vehicle system controller for increasing fuel economy by exercising fuel cutoff during decelerations and stops. The system varies the extent of the cutoff and interaction of the electric machine (MoGen) with the internal combustion engine to maximize fuel saving while not sacrificing passenger comfort, driveability, and component longevity (e.g., battery life).

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 is a diagrammatic view of a hybrid vehicle drive system including the present invention;

Figure 2 is an electrical schematic of a hybrid vehicle powertrain;

Figure 3 is a flow chart illustrating portions of a control algorithm for determining fueling RPM and amount of prime pulse for a hybrid vehicle;

Figure 4 is a graph illustrating engine speed profile during a starting sequence;

Figure 5 is a flow chart illustrating portions of a control algorithm for an engine starting system; and

Figure 6 is a flow chart illustrating portions of a control algorithm for determining the degree of hybridization of the vehicle.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A hybrid vehicle employing a motor generator or "MoGen" in a hybrid system allows many new and unique forms of powertrain control. Accordingly, it is advantageous to determine the status of numerous components of a hybrid system in order to most efficiently utilize all facets of the powertrain control.

For example, and when a hybrid vehicle is decelerating or is stopped, and a control system in accordance with an exemplary embodiment of the present invention is employed, the fuel flow to the engine is shut off to improve fuel economy. Therefore, it is desirable to have the status of the hybrid vehicle components inputted into the control system.

A MoGen system is implemented to enable this fuel-cutoff feature without sacrificing driveability. From a stop, upon brake-pedal release, the MoGen system creeps the vehicle forward while turning the gas engine to start it. Once the engine is running, the MoGen acts as a generator to supply the vehicle's electrical power requirements as well as recharging an electrical storage medium or battery pack. When the engine is off, the vehicle's electrical loads (fans, radio, etc.) are supported by a battery system and a DCDC converter, the MoGen also acts as a motor during fuel-off deceleration downshift to synchronize the engine and transmission speeds.

The control system according to an exemplary embodiment of the present invention may be used in the environment described with reference to Figure 1. The control system controls the fuel efficiency of a hybrid

vehicle drive system 10. Of course, the control system may be used with other hybrid drive train configurations. Hybrid vehicle drive system includes a gas engine 12, a torque converter 14 and a multi-speed automatic transmission 16.

The hybrid drive system 10 further includes a motor generator 18 operatively connected to the front end of the engine by a direct belt or chain drive 20 for providing a drive path to a crankshaft 22 of engine 12. Motor generator 18 is operatively associated with a controller 24 for selectively operating motor generator 18 during start or to produce generated power for charging an array of batteries 26.

An engine and transmission controller 28 is associated with a brake-pressure sensor 30 that directs a signal to controller 28. A suitable DCDC converter 32 is provided to direct higher voltage charging power from the motor generator 18 to a low voltage accessory system, during generator operation.

The system includes an over-speed locking and forward speed freewheeling one-way clutch assembly as described in U.S. Serial No. 09/483,987, filed January 8, 2000, the contents of which are incorporated herein by reference thereto, operatively connected between the impeller or pump of the torque converter 14 and the turbine thereof.

The transmission 16 includes known gear sets, clutches and brakes operative to provide a number of drive speed ratios between the engine 12 and a vehicle drive system 34 such as the illustrated differential 36 and drive wheels 38 and 40, it being understood that the drive wheels can be front or rear drive wheels and that the drive system can be modified to include various forms of power transfer to and from either front or rear drive wheels or both as desired. Multi-speed transmissions 16 are well known and as such a complete description thereof is not required for purposes of understanding the configuration and operation of the present invention.

In addition, and as an alternative embodiment, the motor generator can be mounted directly to the crankshaft between the engine and the transmission.

For a full understanding of the operation of the modified torque converter, reference is made to United States Patent 6,254,507.

When combined with an electric motor generator 18 having its rotor connected mechanically to the crankshaft of a vehicle, such an arrangement can take advantage of back drive from the vehicle wheels to the engine, as occurs during vehicle coasting operations, to drive the rotor of the generator 18 during a regenerative phase of operation where the controller 24 conditions the motor generator 18 to direct charging current from the motor generator 18 to charge the batteries 24. During such coasting, in addition to using the vehicle momentum to recharge the batteries, it is desirable to cut off fuel flow to the gas engine by use of an aggressive fuel control algorithm. Such operation, however, when using known torque converter designs is not optimal in that the fluid coupling action of the torque converter and/or slip in the lock-up clutch can cause the engine speed to drop below the transmission coasting speed, and when fuel is cut off, the engine can stall. In such cases, the battery charge produced during coasting and the battery charge required for the electric starter motor can result in a net energy loss. Hence, the advantage of a motor generator arrangement is not fully realized.

The powertrain controller has an engine controller that includes a dashboard or control panel indicator such as a light indicative of the hybrid system being active as shown by reference numeral 42 in Figure 1. The powertrain controller includes an engine and transmission control microprocessor 28 that is inputted with engine output speed Ne, transmission states, vehicle speed Nv, intake manifold air pressure MAP, brake sensor signal, and throttle position TP and is programmed in response to such

signals to deliver fuel and engine spark to control engine acceleration and speed.

In accordance with an embodiment of the present invention, a control system determines the Degree of Hybridization of the vehicle. "Degree of Hybridization" relates to the level or degree to which the MoGen hybrid system interacts with or replaces the normal functions of an internal combustion engine.

The control system controls the degree of hybridization in order to maximize fuel efficiency.

In addition, and since the MoGen system is in constant mesh with the internal combustion engine, the MoGen system can be used to optimize control for all internal combustion engine operational modes. Additionally, the enhanced control of charging capabilities allows a much more efficient control methodology including fuel efficiency. Therefore, in accordance with the increased control capabilities, a control system must exist to take advantage of the increased opportunities offered by the MoGen hybrid hardware.

Referring now to Figure 2, an electrical schematic of a MoGen hybrid powertrain 50 is illustrated.

This hybrid powertrain system uses "Excess Regen" determined through a single current-measuring device (e.g., shunt) as the main variable to manage the battery SOU (state-of-usage) and SOC (state-of-charge). The electrical power control system and the mechanical architecture dynamically change among four different modes of battery SOU to maintain battery SOC, enhance battery longevity, maintain vehicle driveability, and improve engine responsiveness. The modes are identified as follows: Excess Regen; Zero Excess Regen; MoGen Neutral; and Motoring Discharge.

For purposes of explanation and referring to Figure 2, it is assumed that the system operates at a nominal 36 Volts. Of course, it is

contemplated in accordance with the present invention that the system can operate at voltages greater or less than 36 Volts.

A first battery, battery B1, is chassis grounded, and an additional two batteries B2 and B3 are all connected in series as shown in Figure 2. The respective voltages across each battery (B1, B2 and B3) is identified as V1, V2, and V3. As an alternative, a single 36V battery module with three posts (Ground, 12V, 36V) can also be used, as well as a 36V module and a separate 12V module.

A "DCDC converter" 52 converts the 36V bus down to the conventional 12V to power, in parallel with B1 and an Under Hood Junction Box 54 (UHJB).

An alternative system utilizes more or fewer battery modules depending on the module voltage (e.g., 2V, 6V, 8V, 12V, etc.) and can also be configured with an isolated as well as a non-isolated DCDC converter.

In conjunction with the Excess Regen System, the SOC balance between the chassis-grounded module and the others is controlled by the system described in U.S. Serial No. 09/659,395, filed September 11, 2000, the contents of which are incorporated herein by reference thereto.

The MoGen drive system is powered by a higher voltage (e.g., 36V nominal instead of the conventional 12V nominal system) battery pack. As shown in Figure 2, the 36V bus is connected to a motor controller 56 that regulates the MoGen power. When the MoGen is in motor mode, the battery pack sees the motor controller as a load (drawing current out of the batteries). However, when the MoGen is in generator mode, the battery pack sees the motor controller as a charger. In addition to the motor controller, the 36V battery pack powers the DCDC converter. The DCDC converter transforms the 36V down to the conventional 12V for powering the standard automotive accessories (e.g., fans, radio, etc.).

The arrangement shown in Figure 2 uses a non-isolated DCDC converter, thus the shunt is positioned on the high side. The MoGen shaft is

connected to the internal combustion engine and the arrows indicate current flow.

The battery SOU or mode of operation of the MoGen system can dynamically change among four states:

1. Excess Regen;
2. Zero Excess Regen;
3. MoGen Neutral; and
4. Motoring Discharge.

<u>Excess Regen</u>:

Of the Total Regen i_{tr} provided by the MoGen, a portion powers the DCDC converter i_{DCDC} and the remaining Regen (or the Excess Regen i_{ER}) recharges the battery pack. This is the state that the system will default to for a large majority of its operation time (e.g., cruising on highway).

If the battery pack SOC is low, the Excess Regen can be commanded up to a set value; if the battery pack SOC is high, the Excess Regen is tapered down to a minimal value. The upper limit for Excess Regen may be determined by the drivability of the vehicle; i.e., if the Excess Regen is too high, the powertrain will feel sluggish. This SOU is active: Anytime the battery SOC is not full, and MoGen is being backdriven by the internal combustion engine or the transmission.

<u>Zero Excess Regen:</u>

The MoGen provides just enough Total Regen to power the DCDC converter ($i_{TR} = i_{DCDC}$). The Excess Regen to charge the battery pack is zero ($i_{ER}=O$). Zero Excess Regen is used when the batteries are fully charged. Determination of when the batteries are fully charged can be estimated from charge voltage, charge amperage, open-circuit voltage, and charge integration coupled with the Peukert relationship. In actuality, since the DCDC converter loads can be constantly fluctuating, the excess regen cannot be held to exactly

zero. It is preferable to slightly overcharge than to consistently undercharge the battery pack. Thus, even when Zero Excess Regen is commanded, the system is biased toward slight Excess Regen. This SOU is active when:

a. The battery SOC is full.

b. After crank starting the ICE when the coolant temperature or the SOC is medium or high, the MoGen is controlled to Zero Excess Regen after the MoGen is done motoring the ICE, but before the combustion is deemed fully stabilized.

<u>MoGen Neutral:</u>

In this state the MoGen is free spinning, thus $i_M = i_{TR} = 0$. Since the accessory loads are still supported by the DCDC converter, i_{DCDC} is still positive. The power for i_{DCDC} is provided by i_{DCDC+M}, thus the battery pack is being discharged. This SOU is active when:

a. During some shift events. Neutral is commanded to eliminate aliasing, due to possible engine torque variability, of the transmission adaptives.

b. After crank starting the ICE when the coolant temperature or the SOC is low, the MoGen is controlled to Neutral after the MoGen is done motoring the ICE, but before the combustion is deemed fully stabilized to minimize engine load.

c. Vehicle is keyed-on when the internal combustion engine is off.

<u>Motoring Discharge:</u>

The MoGen delivers mechanical work to the engine. The electrical charge flowing out of the battery pack i_{DCDC+M} is the sum of this MoGen motoring load i_M and the DCDC converter input load i_{DCDC}. This can occur under the following conditions:

a. During key-up crank start.

b. During a hybrid launch from a stop.

c. During a fuel-off downshift (U.S. Serial No. 09/551,460).

d. During an Inertia Eliminator routine.

In accordance with an exemplary embodiment of the present invention, a control system is employed for the initial engine crank-starting upon key up.

Unique features of this system are:

1. The MoGen system can dynamically reapply electric motoring power during an engine start attempt, in addition to increasing IAC (idle-air-control) opening and slewing spark timing.

2. The MoGen system can modulate between four states (motoring, zero excess-regen, neutral, and regen) of MoGen power during a starting flare.

3. The Smart DCDC converter (U.S. Serial No. 09/659,395) does not allow battery B1's voltage to get under the minimum voltage required for the vehicle's computers and accessories.

4. The engine speed at which fuel and spark are delivered during a start is a function of battery state-of-charge and engine coolant temperature to improve tailpipe emissions, cranking smoothness, and to reduce excessive flare above the target idle speed.

The MoGen is constantly engaged to the internal combustion engine, via a belt or through direct mount to the transmission. This is different from a conventional engine starting system in which the starter motor pinion gear is engaged to the engine ring gear by a solenoid. In a conventional system, once the engine is running by combustion, the starter motor pinion is disengaged and cannot be smoothly re-engaged without the engine coming to rest.

To enable the starting system in accordance with an exemplary embodiment of the present invention, all of the following criteria must be met:

1. Key in the START position.

2. Engine speed =0.

3. Transmission in P (park) or N (neutral), or clutch disengaged for a manual transmission.

4. Engine, transmission, and MoGen controllers live.

5. Battery voltage balance among the modules (e.g., three for a 36V nominal system) must be within a certain range.

6. Anti-theft system has not been triggered.

Of course, the criteria for an enclosed starting system may be varied to modify or include alternative criteria.

Referring now to Figure 3, a flow chart depicting a control algorithm 70 for determining fueling RPM and amount of engine prime pulse for the MoGen system is illustrated. The engine speed at which the fuel (and amount of fuel) and spark are delivered for the engine start is a function of battery SOC and engine coolant temperature (ECT). For a number of SOC and ECT levels (e.g., low, med., high SOC), the engine speed for start is adjusted to improve cranking smoothness and emissions.

The computer algorithm is resident upon an engine control module or other appropriate micro-controller which will receive the necessary inputs and be capable of controlling the appropriate vehicle system.

During a starting sequence, a first decision node 72 determines whether the battery's state-of-charge (SOC) is low (e.g., below a predetermined value). If the battery's SOC is not low, a decision node 74 determines whether the SOC is medium (e.g., below a predetermined value higher than the predetermined value of decision node 72).

If decision node 74 determines that the battery SOC is greater than the predetermined value of decision node 74, a decision node 76 determines whether the engine coolant temperature (ECT) is below a predetermined calibration constant representing a low value. If decision

node 76 determines that the engine coolant temperature is not below the predetermined value of decision node 76, the engine firing is initiated at a high RPM (e.g., 600 rpm) without a prime pulse. This firing is represented by box 78.

Alternatively, and if decision node 76 determines that the engine coolant temperature is below the predetermined calibration constant of decision node 76, the engine firing is initiated at a low RPM (e.g., 100 rpm) with a prime pulse. This firing is represented by box 80.

Alternatively, and if decision node 74 determines that the battery state-of-charge is below the calibration constant of decision node 74, a decision node 82 determines whether the engine coolant temperature is low (e.g., below a calibration constant). If decision node 82 determines that the engine coolant temperature is below the calibration constant, a decision node 82 the engine firing is initiated at a low RPM (e.g., 100 rpm) with a prime pulse. This firing is represented by box 80.

Alternatively, and if decision node 82 determines that the engine coolant temperature is above the calibration constant of decision node 82, a decision node 84 determines whether the engine coolant temperature is at a medium temperature (e.g., below a calibration constant representing medium temperature).

If decision node 84 determines that the engine coolant temperature is at the medium range, the engine firing is initiated at a medium RPM (e.g., 400 rpm) with a minimum prime pulse. This firing is represented by box 86.

Alternatively, and if decision node determines that the engine coolant temperature is above the medium range, the engine firing is initiated at a medium RPM (e.g., 400 rpm) with a minimum prime pulse. This firing is represented by box 88.

If decision node 72 determines that the battery's state-of-charge is below the calibration constant of decision node 72 (e.g., low state-of-

charge), a decision node 90 determines whether the engine coolant temperature is also low (e.g., below a calibration constant representing a low engine coolant temperature). If so, the engine firing is initiated at a low RPM (e.g., 100 rpm) with a prime pulse. This firing is represented by box 80.

Alternatively, and if decision node 90 determines that the engine coolant temperature is above the calibration constant of decision node 90, a decision node 92 determines whether the engine coolant temperature is in a medium range. If so, the engine firing is initiated at a low RPM (e.g., 100 rpm) with a medium prime pulse. This firing is represented by box 94.

Alternatively, and if decision node 92 determines that the engine coolant temperature is above the calibration constant of decision node 92, the engine firing is initiated at a low RPM (e.g., 100 rpm) with a minimal prime pulse. This firing is represented by box 96.

For example, if the SOC is high and the ECT is low, the engine firing initiates at a low engine speed (e.g., 100 rpm) with a prime pulse, but if the SOC is high and the ECT is medium, the engine firing can initiate at a higher engine speed without a prime pulse, thereby reducing tailpipe emissions.

Another example is if the SOC is low and the ECT is high, the firing can initiate at a low rpm with a minimal prime pulse.

It is, of course, contemplated that in accordance with an exemplary embodiment of the present invention, the calibration constants and starting sequence parameters may vary, as application conditions require.

If the engine cranking speed is so low (e.g., if both the SOC and ECT are very low) that the ignition system is in an open-loop fixed-spark-timing routine (e.g., 10 degrees Before Top Dead Center "BTDC"), the system will attempt to fire the engine at the lowest possible engine speed at which the combustion will not pulse the engine backwards. This ensures that the MoGen is motoring as effectively as possible.

Referring now to Figure 4, the MoGen motoring power is ramped down when the engine start is deemed successful. An engine start is successful if both of the following are satisfied:

1. The engine is firing above the Upper Flare Speed Threshold (Figure 4) for greater than a set continuous time, Upper Flare Time.

2. The engine is firing above the Lower Flare Speed Threshold (Figure 4) for greater than a set continuous time, Stable Run Time.

To determine if the engine has been properly started, the powertrain computer monitors the engine speed flare over time. If the engine speed surpasses the Upper Flare Threshold for a set time Upper Flare Time, the MoGen motoring power is ramped down to zero excess regen. If the MoGen command were slewed to higher values of excess regen, the extra retarding torque imposed on the engine crank can drag down the engine speed.

The Speed Thresholds and time calibrations are set as a function of engine coolant temperature. When the engine is cold, the probability of unstable combustion is higher; therefore, the required engine speed threshold and time above that threshold before MoGen motoring power is reduced and is set higher than in a warm engine scenario.

If the battery SOC is deemed sufficiently high, and the engine speed declines after the initial flare is deemed too steep, the MoGen can first be set to neutral (negative excess regen since all the DCDC converter input power is drawn from the 36V battery bus). Setting the MoGen to neutral lets it spin freely, thus not actively contributing to the engine deceleration.

If before or after the MoGen is set to neutral (or zero excess regen), and the engine speed falls below the Lower Flare Speed Threshold, the MoGen motoring power is increased or reapplied to aid the combustion power to raise the engine speed back above the lower flare threshold. This is done in conjunction with increasing the IAC opening and optimizing spark timing for increased internal-combustion engine power (regardless of driver

throttle command). The start is deemed successful if the engine speed stays above the Lower Flare Speed Threshold for a continuous time exceeding a preset value (Stable Run Time), which is a function of coolant temperature. If the engine speed droops below the Lower Flare Speed Threshold, the Stable Run Time value is reset.

Once the driver momentarily turns the ignition key to START or CRANK (i.e., the driver need not continuously hold the key in the start position), the hybrid powertrain control system takes over to smoothly and efficiently start the engine.

If the MoGen cannot prevent the engine from stalling, the next engine starting sequence must start from an ignition key position other than the "start" or "crank" position. For example, if the driver continuously holds the key in the start position (though the driver did not have to) during the unsuccessful start attempt, the key must be released back to the "run," "accessory" or "off" position for the starting system to make its next attempt.

The engine start is abandoned if any of the following are true:

1. Transmission taken out of P (park) or N (neutral).

2. The ignition key is removed, or turned to ACCESSORY or OFF (i.e., not in RUN or START).

3. Maximum cranking time threshold is exceeded.

When the MoGen is spinning with the engine firing, the MoGen acts as a generator to power the DCDC converter and to charge the batteries. The "excess regen" is the MoGen generating power used to recharge the batteries. The DCDC converter converts the 36V nominal MoGen bus voltage down to the standard 12V nominal vehicle system voltage to power the ignition system, fuel pump, transmission solenoids, etc.

As discussed in the Battery Module Balancing application (U.S. Serial No. 09/659,395), the contents of which are incorporated herein by reference thereto, the DCDC converter output balances the battery state-of-

charge (SOC) with the parallel-connected chassis-grounded battery (B1). An exception to the battery-balancing routine during engine cranking is that the DCDC converter strives to raise its voltage output to B1 so that its voltage stays above a set threshold (e.g. 9V). This is necessary in order to keep the powertrain computer, and thus the ignition system, active during the crank procedure.

Referring now to Figure 5, a flow chart illustrates portions of a computer algorithm for a MoGen engine starting system 100, given a SOC and ECT. It is noted that system 100 runs simultaneously with control algorithm 70 during a starting event. The computer algorithm is resident upon an engine control module or other appropriate micro-controller which will receive the necessary inputs and be capable of controlling the appropriate vehicle system.

In accordance with an exemplary embodiment of the present invention, starting system 100 includes a decision node 102 that determines whether all of the conditions has been met for a starting of the hybrid vehicle to take place. As previously discussed, decision node 102 determines whether all of the following criteria have been met: Key in the START position; Engine speed = 0; Transmission in P (park) or N (neutral), or clutch disengaged for a manual transmission; Engine, transmission, and MoGen controllers live; Battery voltage balance among the modules (e.g., three for a 36V nominal system) must be within a certain range; and Anti-theft system has not been triggered.

If all of the aforementioned criteria have been met, a step 104 ensures that the start system has been enabled and the key has been turned to a crank position. A decision node 106 determines whether the maximum time has been exceeded; if so, the system is returned to an initial state prior to decision node 106. Alternatively, and if the maximum time of decision node 106 has not been exceeded, a step 108 instructs the power to the MoGen to be ramped up in order to provide cranking power to the system.

A decision node 110 determines if any one of the following is true: vehicle shifter out of park or neutral; ignition key position is out of a run or start position; an error (e.g., fault detection) has been detected; and in the case of a manual transmission the clutch pedal is no longer depressed or a clutch is no longer engaged, a step 112 instructs the system to abort the crank up procedure.

Alternatively, and if decision node 110 has found no conditions which would require aborting of the starting sequence, a decision node 114 determines whether the upper flare speed threshold (Figure 4) has been exceeded. If the upper flare speed threshold has not been exceeded, the system returns to the state indicated by decision node 106. Otherwise, a decision node 116 determines whether the upper flare time has been exceeded.

If the upper flare time has not been exceeded, the system returns to the state indicated by decision node 114. Otherwise, a step 118 instructs the MoGen to ramp down.

After step 118, a decision node 120 determines whether the starting sequence as exceeded a maximum allowable time. If so, the system returns to the state indicated by decision node 102. Otherwise, a decision node 122 determines whether the lower flare speed threshold (Figure 4) has been exceeded. If so, a decision node 124 determines whether the lower flare time has been exceeded. If so, a starting sequence is exited.

Alternatively, and if decision node 122 determines that the lower flare speed threshold has not been exceeded, a step 126 raises the MoGen IAC, Slew and Spark. After step 126, the system returns to the state indicated by decision node 120.

Alternatively, and if decision node 124 determines that the lower flare time has not been exceeded, the system returns to the state indicated by decision node 120.

Accordingly, and referring now to Figures 1-5, a starting system employing a MoGen control system in accordance with an exemplary embodiment of the present invention varies the electric motoring power during an engine start attempt wherein the MoGen system is capable of modulating between four states of MoGen power during a starting flare. In order to facilitate this process, the control algorithms illustrated in Figures 3 and 5 are simultaneously utilized during a start event.

The algorithms monitor vehicle operating conditions through a plurality of sensors. Such operating conditions include but are not limited to the following: vehicle speed, engine speed, engine RPM, MoGen state of use, battery state-of-charge, and engine coolant temperature in order to vary the operating condition of the MoGen as well as the vehicle propulsion system during a starting event.

It is, of course, contemplated that in accordance with an exemplary embodiment of the present invention, the above-mentioned predetermined values and starting sequence parameters of the above variable conditions may vary, as application conditions require.

In accordance with an exemplary embodiment of the present invention, a control system determines the Degree of Hybridization of the vehicle. "Degree of Hybridization" relates to the level or degree to which the MoGen hybrid system interacts with or replaces the normal functions of an internal combustion engine.

Controlling the degree of hybridization improves the overall fuel efficiency of the hybrid vehicle. Thus, monitoring conditions of the vehicle and vehicle systems, the control system determines what degree of hybridization the vehicle is in or should be in.

In addition, and since the MoGen system is in constant mesh with the internal combustion engine, the MoGen system can be used to optimize control for many internal combustion engine operational modes. Additionally, the enhanced control of charging capabilities allows a more

efficient control methodology. Therefore, in accordance with the increased control capabilities, the control system takes advantage of the increased opportunities offered by the MoGen hybrid hardware.

The control system varies the extent of engine fuel cutoff and task of electrification as a function of battery state-of-charge, ambient temperature, engine coolant temperature, air conditioner switch position, transmission downshift synchronization requirements and fault diagnostics information.

During a deceleration, the transmission system must perform a downshift so that the transmission will be in the proper gear if the driver wishes to reaccelerate. In order to perform the downshift, the engine speed must be raised between the release of one gear and the engagement of the lower gear. Additionally, when a vehicle is decelerating down a steep grade, the powertrain system may command a downshift at a higher speed than when driving on flat or uphill terrain. At this higher engine speed, the MoGen may not have enough torque to properly perform the speed synchronization. For this reason, under these MoGen-limited conditions, the spark and fuel is blended in (engine is already spinning) during the speed synchronization to aid the MoGen.

To make the operation of the hybrid system as transparent as possible, the added rotational inertia of the MoGen system can be virtually eliminated by powering the MoGen to accelerate itself and its components during rapid throttle-application transients. This "Inertia Elimination" routine makes the powertrain more responsive to driver input. This differs from "power assist" in that the spike of MoGen power only indirectly contributes to vehicle acceleration. With the torque converter clutch open, the inertia eliminator spike of power raises the engine speed more rapidly so that the engine is at a more favorable portion of its torque curve, and thus enabling the vehicle to accelerate better. If the battery's state-of-charge is not sufficiently high, the inertia elimination system is disabled.

Referring now to Figure 6, a flowchart 150 illustrating a computer algorithm for determining the degree of hybridization of the hybrid vehicle is illustrated. The computer algorithm is resident upon an engine control module or other appropriate micro-controller which will receive the necessary inputs and be capable of controlling the appropriate vehicle system.

An initial step or decision node 252 determines whether an initial key up condition (e.g., engine cranking sequence) exists. If so, the vehicle is in an engine start/crank degree of hybridization represented by box 254.

Alternatively, if decision node 252 determines that an initial key-up condition does not exist (e.g., vehicle running or vehicle off), a decision node 256 determines the state-of-charge (SOC) of the vehicle.

If the SOC is low (e.g., below a calibration constant), the vehicle is placed in a no hybridization mode represented by box 258. Alternatively, if the SOC is not low, a decision node 260 determines if the ambient temperature is low (e.g., below a calibration standard). If so, the vehicle is in a no hybridization mode represented by box 258.

Alternatively, if the ambient temperature is not low, a decision node 262 determines if the engine coolant temperature is low (e.g., below a calibration standard). If so, the vehicle is placed in a no hybridization mode represented by box 258.

Alternatively, if the engine coolant temperature is not low, a decision node 264 determines if there are any faults (e.g., system errors detected by other controllers, sensors or control systems). If so, the vehicle is placed in a no hybridization mode represented by box 258.

Alternatively, and if no faults are detected (e.g., all systems clear), a decision node 266 determines whether the air conditioning system of the vehicle is on. If so, a decision node 268 determines if the motor generator performance would be a limitation to executing an electric downshift synchronization (MoGen). If so, the vehicle is placed in a

deceleration-only hybrid mode with fuel-aided downshifts and without inertia eliminator represented by box 270. This degree of hybridization has been determined to be the most energy- and fuel-efficient mode given the vehicle parameters required to reach this point.

Alternatively, and if decision node 268 determines that the vehicle is not in a motor generator limit downshift mode, the vehicle is placed in a deceleration-only hybrid mode without inertia eliminator represented by box 272. This degree of hybridization has been determined to be the most energy- and fuel-efficient mode given the vehicle parameters required to reach this point.

On the other hand, if decision node 266 determines that the air conditioning system is not on and decision nodes 256-264 have interpreted the vehicle conditions necessary to reach decision node 266, a decision node 274 determines whether the battery state-of-charge is in a medium range (e.g., defined by a calibration constant representing a medium percentage state-of-charge). If decision node 274 determines that the hybrid vehicle batteries are in a medium state-of-charge, a decision node 276 determines whether the MoGen is in a limited downshift state. If so, the vehicle is placed in a deceleration-only hybrid mode with fuel-aided downshifts and without inertia eliminator represented by box 270. Otherwise, the vehicle is placed in a deceleration-only hybrid mode without inertia eliminator represented by box 272. This degree of hybridization has been determined to be the most energy- and fuel-efficient mode given the vehicle parameters required to reach this point.

If, on the other hand, decision node 274 determines that the vehicle's state-of-charge is not in the medium range, a decision node 278 determines whether the ambient temperature is in a medium-range (e.g., represented by a pair of calibration constants for defining the medium range). If so, a decision node 280 determines whether the MoGen is in a limited downshift state. If so, the vehicle is placed in a deceleration-only

mode with fuel-aided downshift with inertia eliminator represented by box 282. Otherwise, the vehicle is placed in a deceleration-only mode with inertia eliminator and no fuel-aided downshift, represented by box 284. This degree of hybridization has been determined to be the most energy- and fuel-efficient mode given the vehicle parameters required to reach this point.

If, on the other hand, decision node 278 determines that the ambient temperature is not in the medium range, a decision node 286 determines whether the engine coolant temperature is in a medium range (e.g., a range defined by a pair of calibration parameters). If so, a decision node 288 determines whether the MoGen is in a limited downshift state. If so, the vehicle is placed in a deceleration-only mode with fuel-aided downshift with inertia eliminator represented by box 282. This degree of hybridization has been determined to be the most energy- and fuel-efficient mode given the vehicle parameters required to reach this point.

Otherwise, the vehicle is placed in a deceleration-only mode with inertia eliminator and no fuel-aided downshift, represented by box 284. This degree of hybridization has been determined to be the most energy- and fuel-efficient mode given the vehicle parameters required to reach this point.

If, on the other hand, decision node 286 determines that the engine coolant temperature is not in the medium range, a decision node 290 determines whether the MoGen is in a limited downshift state. If so, the vehicle is placed in a full hybrid mode with fuel-aided downshift represented by box 292. This degree of hybridization has been determined to be the most energy- and fuel-efficient mode given the vehicle parameters required to reach this point.

Otherwise, the vehicle is placed in a full hybrid mode represented by box 294. This degree of hybridization has been determined to be the most energy- and fuel-efficient mode given the vehicle parameters required to reach this point.

The control system has been segmented into the following eight discrete degrees:

1. Degree 1 - Full Hybrid (represented by box 294): Fuel cutoff exercised on decelerations and stops (engine off), with MoGen-aided downshift engine-speed synchronization and the Inertia-Eliminator routine active.

2. Degree 2 - Full Hybrid with Fuel-Aided Downshifts (represented by box 292): Fuel cutoff is exercised during decelerations and stops (engine off), Inertia Eliminator is active, but downshift engine-speed synchronization is performed by both combustion and electric power.

3. Degree 3 – Deceleration-Only Hybrid (represented by box 284): Fuel cutoff exercised only on decelerations. Fuel delivery is restarted just before the Drop-to-Neutral speed. The downshift engine speed synchronization is performed by the MoGen, and Inertia Eliminator is active.

4. Degree 4 – Deceleration-Only Hybrid without Inertia Eliminator (represented by box 272): Same as "Deceleration-Only Hybrid" but Inertia Eliminator is not active.

5. Degree 5 - Deceleration-Only Hybrid with Fuel-Aided Downshifts (represented by box 282): Fuel cutoff exercised only on decelerations. Fuel delivery is restarted just before the Drop-to-Neutral speed; the downshift engine speed synchronization is performed by both combustion and MoGen. Inertia Eliminator is active.

6. Degree 6 - Deceleration-Only Hybrid with Fuel-Aided Downshifts, without Inertia Eliminator (represented by box 270): Same as "Deceleration-Only Hybrid with Fuel-Aided Downshifts" but Inertia Eliminator is not active.

7. Degree 7 - No Hybridization (represented by box 258): No fuel cutoff is exercised during decelerations or stops, Inertia Eliminator is not active, and MoGen-aided downshift synchronization is disabled.

8. Degree 8 - Engine Start/Crank (represented by box 254): MoGen unit is used as a starter motor for the internal combustion engine. In this state, the algorithms of Figures 3-5 are also employed.

The difference between Degree 1 (box 294) and Degree 2 (box 292) is that in Degree 2, the speed synchronization is performed by both electric power and combustion power.

The difference between Degree 3 (box 284) and Degree 4 (box 272) is the implementation of the "Inertia Eliminator" concept.

The difference between Degree 5 (box 294) and Degree 6 (box 270) is the deactivation of the "Inertia Eliminator" concept in Degree 6.

For example, the utilized degree of hybridization is a function of the following variable conditions.

1) Battery State-of-charge (SOC):
   a) Low (e.g., SOC < 50%)
   b) Med (e.g., SOC = 50-75%)
   c) High (e.g., SOC >75%)
2) Ambient Temperature (Tamb):
   a) Low (e.g., Tamb < 5 deg. C)
   b) Med (e.g., Tamb = 5-20 deg. C)
   c) High (e.g., Tamb> 20 deg. C)
3) Engine Coolant Temperature (ECT):
   a) Low (e.g., ECT < 0 deg. C)
   b) Med (e.g., ECT = 0 - 50 deg. C)
   c) High (e.g., ECT> 50 deg. C)
4) A/C — Heater Blower setting:
   a) Low
   b) Med
   c) High
5) A/C request state (on or off).

6) Downshift engine synchronization speed requirement.

7) Ignition key position.

8) Overrides based on diagnostics, failure modes, faults.

Of course, it is contemplated that in accordance with an exemplary embodiment of the present invention, the aforementioned calibrations constant may vary, by way value changes, supplementation and elimination.

The algorithms of Figures 3, 5 and 6 are contemplated for use simultaneously with each other or alternatively in any combination thereof including a stand-alone feature.

While the invention has been described with reference to a preferred embodiment, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.